PHENIX Highlights.

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Abstract.
    Recent highlights of measurements by the PHENIX experiment at RHIC are presented.

The purpose of this talk was to highlight some of the most interesting recent results from PHENIX, all of which are described in more detail in other contributions to these proceedings.
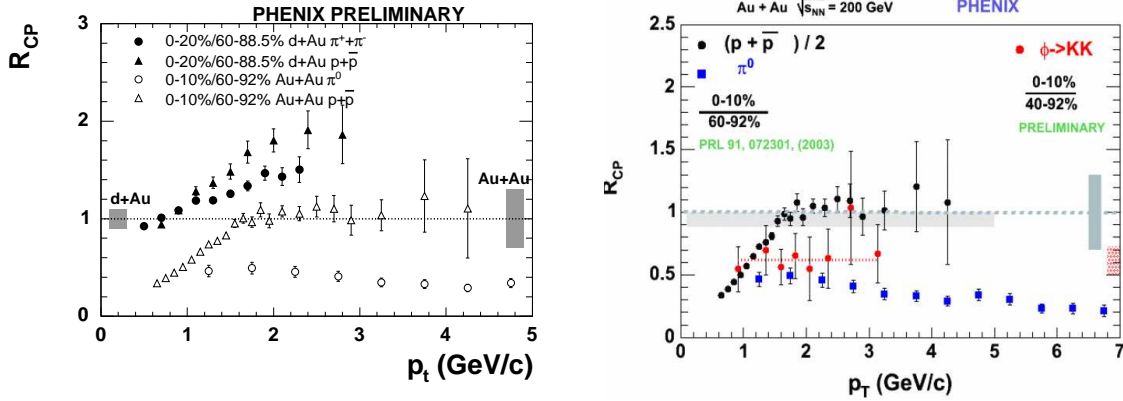

Figure 1. Left: pions are three times more heavily suppressed than protons in central Au+Au collisions at 200 GeV, while pion yields are only 25% lower than proton yields in d+Au in d+Au collisions. Right: ϕ meson suppression is similar to π^0 suppression in central Au+Au collisions.

A comparison versus centrality of unidentified charged hadron data and π^0 data for Au+Au and d+Au collisions shows that hadron yields are enhanced at high collision centrality in d+Au, but suppressed as centrality increases in Au+Au [1]. Thus entrance channel effects can not explain the strong hadron suppression in central Au+Au collisions. One very interesting feature is that the nuclear modification factor for unidentified charged hadrons is significantly larger than that for pions for p_T of about

2-5 GeV/c, indicating that protons are less strongly suppressed than pions in that momentum range.

To investigate whether the observed enhancement of protons over pions in the medium p_T range in central Au+Au collisions can be an entrance channel effect, identified charged particle data for p+p, d+Au and Au+Au collisions have been compared [2], as shown in fig. 1. It is found that although the Cronin enhancement in d+Au is slightly larger for protons, the effect is too small to explain the factor of three difference in yields in central Au+Au collisions. Thus the enhancement must be attributed to the conditions formed in central Au+Au collisions. In the same figure, it is shown that the ϕ suppression is comparable with that of the pion, providing evidence that the difference in suppression between protons and pions is related to baryon number, not mass [3].
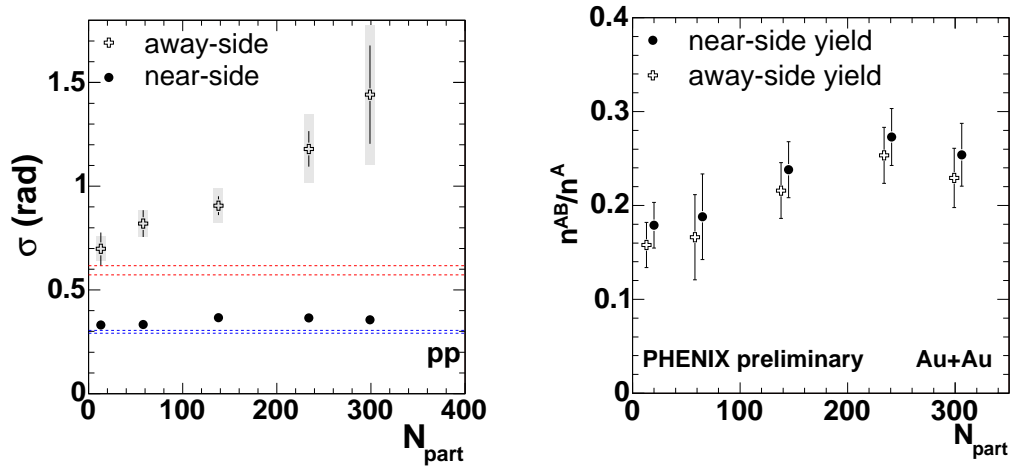

Figure 2. Left: half-widths of the near side and away side peaks in the two-particle azimuthal correlations as a function of centrality. Right: The near and away side associated particle yields as a function of centrality.

PHENIX has studied the properties of jets in p+p, d+Au and Au+Au collisions at 200 GeV using two-particle azimuthal correlations in which the trigger particle is assumed to be the leading particle from a high p_T jet [4] and the second particle is either from the same jet or the recoil jet. Fig. 2 shows the 200 GeV Au+Au centrality dependence of the measured widths (characterized by $< j_{Ty} >$) of the near side jet correlation function and (characterized by $< z >< K_{Ty} >$) the far side jet correlation function. The near side width is seen to be essentially constant while the far side width increases markedly with centrality. Also shown is the centrality dependence of the near and away side associated yields per trigger particle, integrated over the full (gaussian) distribution in each case. The associated yields are seen to be very similar to each other and to rise somewhat with centrality.
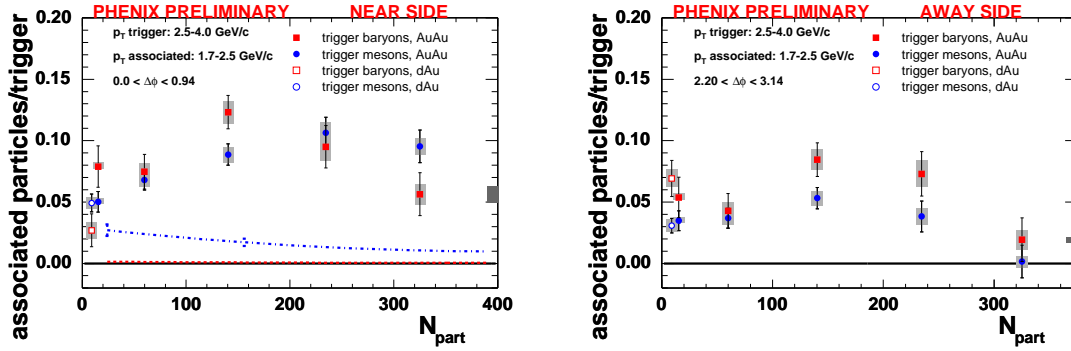
Figure 3. Left: The near side associated yields as a function of centrality when the trigger particle is identified as a meson or baryon. Right: The away side associated yields for meson and baryon trigger particles.

To investigate the production mechanism for the excess baryons observed at 2-5 GeV/c in central Au+Au collisions, PHENIX has studied azimuthal two-particle correlations with one of the particles identified as a baryon or meson [5]. If the intermediate p_T trigger particles are produced by fragmentation, they should show correlations with other particles in the jet. If they are produced by coalescence of flowing thermal partons, they should not show correlations with lower momentum particles. Fig. 3 shows that the near side associated yields per trigger are very similar for meson and baryon triggers. The theory curves show the expected behavior for coalescing thermal quarks from a model. Also shown is the away side yield per trigger particle, which shows a larger yield on the away side when a baryon is the trigger particle. The results seem to be inconsistent with models in which medium p_T hadron production is dominated by thermal quark coalescence. Models which allow coalescence of thermal partons with jet fragments may do better.

PHENIX has observed small nonrandom fluctuations in event-by-event averaged p_T values from 200 GeV Au+Au collisions. A PYTHIA based simulation study has shown that their p_T and centrality dependence can be explained if they are caused by correlations due to jets, when proper account is taken of the measured jet suppression factor [6]. Fig. 4 shows the measured fluctuations from Au+Au data compared with a model made by embedding high p_T PYTHIA events into simulated AuAu events. When the model takes account of the observed suppression of pions in central Au+Au collisions (lower curve), it agrees quite well with the data.

HBT radii have been measured by PHENIX from pion-pion, kaon-kaon and proton-proton correlations produced in 200 GeV Au+Au collisions. The fits to the correlations have been made with the so-called partial coulomb corrections (which allow for the fact that the data contain some particles that were not directly produced in the collision). The results, which extend out to a k_t of 1.2 GeV, show that all three of the hadron pairs studied yield consistent radii, and the radii fall with m_t as expected for collective flow. The ratio of R_{out}/R_{side} is consistent with one, implying a short emission time that
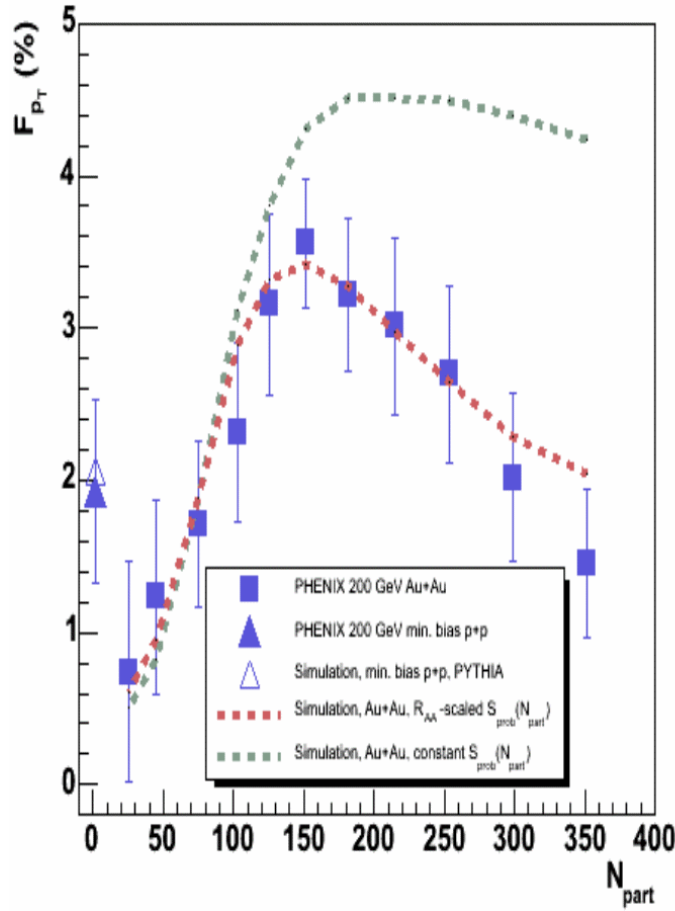
Figure 4. Measured fluctuations in the average p_T versus centrality for Au+Au collisions. F_{PT} is the percent difference between the standard deviations of the average p_T of the data and the average p_T of a mixed event sample. See the text for a description of the curves.

seems inconsistent with expectations if a QGP is formed [7].

Fig. 5 shows a summary of PHENIX direct photon yield measurements for 200 GeV Au+Au collisions [8], compared with a binary collision scaled pQCD estimate. These first direct photon measurements from RHIC are presented as a measured ratio of photon yield to π^0 yield, divided by the expected ratio of photon yield to π^0 yield if there were no direct photons. The use of this double ratio causes some experimental systematic errors to cancel. The results show that direct photon production in 200 GeV collisions is well described by pQCD - ie. unlike hard partons, hard photons are not suppressed in central Au+Au collisions at RHIC. These data, from Run 2, are not yet precise enough to allow any conclusions about possible thermal direct photons at RHIC.

PHENIX has recently developed new techniques for measuring hadrons in the muon arms. These techniques have been used [9] to study the nuclear modification factor for hadrons in d+Au collisions in the range $-2 < \eta < 2$. Fig. 6 shows the ratio of central
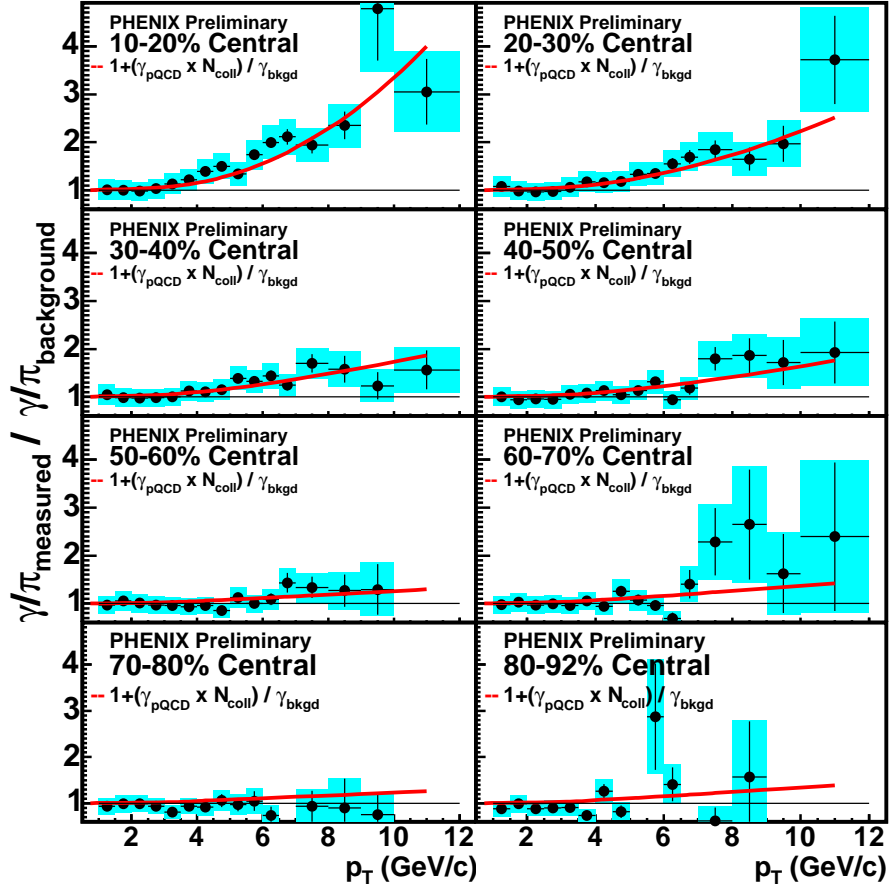
Figure 5. Direct photon signal for 200 GeV Au+Au collisions as a function of centrality. See the text for a description of the double ratio. The heavy solid curve is a pQCD estimate.

to peripheral yields (R_{CP}) for hadrons in three centrality bins in the central and muon arms. The observed suppression on the deuteron-going side (positive rapidity) and enhancement on the Au-going side (negative rapidity) are qualitatively consistent with parton shadowing (or saturation) at small x in the Au nucleus, and anti-shadowing at large x, all superimposed on a Cronin enhancement.

The observation of strong suppression of high p_T light quark hadrons at 200 GeV in central Au+Au collisions at RHIC has led to interest in measuring the spectral shape for heavy quark mesons. PHENIX has measured single electron spectra at midrapidity in 200 GeV p+p, d+Au and Au+Au collisions [10] as a means of studying open charm (D meson) and open beauty (B meson) production in these reactions. The electron spectra, after subtraction of electrons from photon conversion and light quark decays, are assumed to be due to heavy quark decays. The d+Au electron spectra are consistent, within errors, with the binary scaled p+p spectra. This indicates that there is no strong initial state modification of the gluon distribution function in Au in the x range $10^{-2}-10^{-1}$. For Au+Au the integrated dN/dy values are consistent with binary scaling
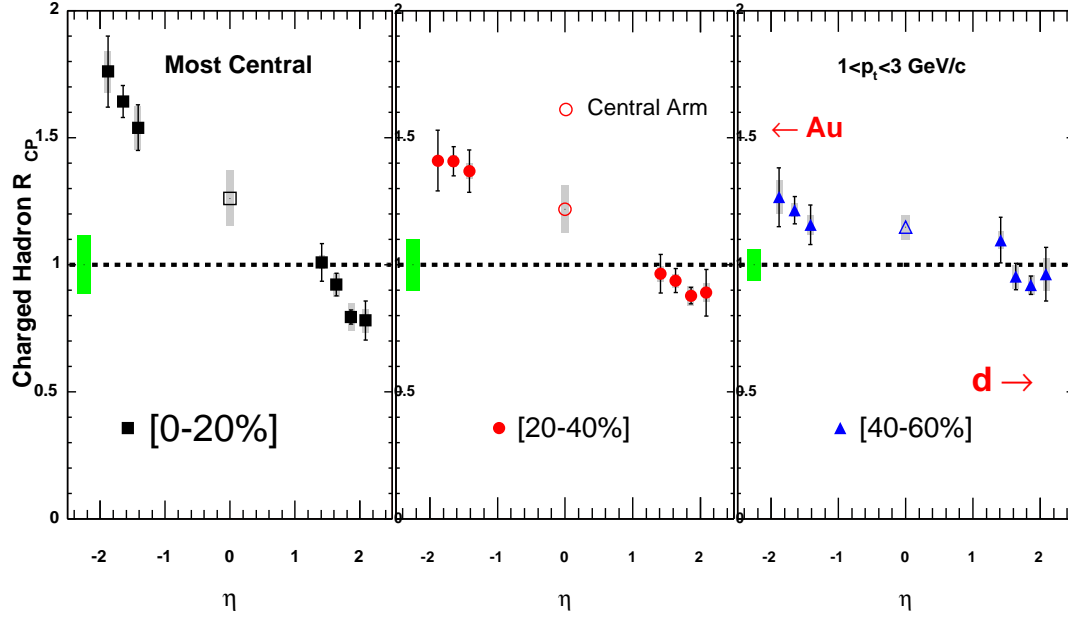
Figure 6. The ratio of binary collision scaled central to peripheral yields for charged hadrons, as a function of rapidity for three centrality bins. The yields inside $1 < \eta < 2$ were measured using punch-through hadrons in the muon identifiers.
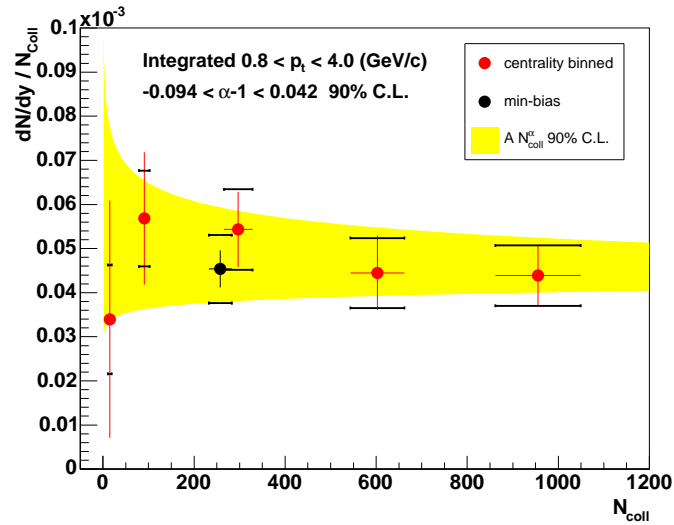

Figure 7. Open charm integrated yields per binary collision for 200 GeV Au+Au.

within errors (see Fig. 7), but nothing can be concluded yet about the energy loss of heavy quarks in central Au+Au collisions, given the precision of the Au+Au data from Run 2.
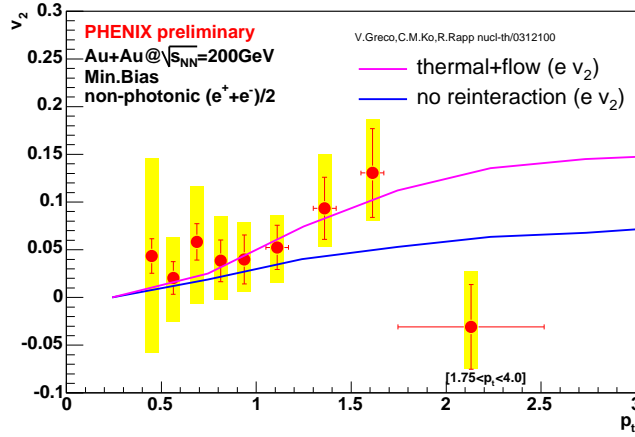
Figure 8. Open charm v_2 for 200 GeV Au+Au collisions, compared with model estimates.

The p_T spectrum alone at medium p_T does not discriminate well between a scenario where the charm quark has minimal interaction with the medium, and a scenario where the charm quark interacts strongly with the medium and participates in hydrodynamic flow. The measurement of v_2 for open charm offers the hope of discriminating between these two scenarios [10]. PHENIX has studied event anisotropy using π^0, photon and electron data [11]. Fig. 8 shows the result of a preliminary analysis of Run 2 Au+Au data to extract the v_2 for non-photonic single electrons (predominantly due to open charm in the p_T range covered by the data). The measurement is compared with a prediction assuming no interaction of charm with the medium, and a prediction assuming thermalization and flow of the charm. The results are inconclusive at the level of precision available from the Run 2 data, but the Run 4 data set is expected to provide two orders of magnitude higher electron yields, as well as single muon measurements.

PHENIX has measured J/ψ production at forward, middle and backward rapidities in 200 GeV p+p and d+Au collisions [12]. The p+p total cross section is extracted, providing the baseline J/ψ production rate in the absence of nuclear effects. The centrality dependence of the J/ψ yield per binary collision in d+Au collisions contains information about how the cross section is modified by the cold nuclear matter present in d+Au collisions. Fig. 9 shows the measured nuclear modification factor $(\sigma_{d+Au}/(N_{coll}\ \sigma_{p+p}))$ in d+Au as a function of the number of binary collisions in the two muon arms, along with some model predictions of the effects of shadowing and anti-shadowing. At low x in the Au nucleus (forward rapidity), the centrality dependence is weak and qualitatively consistent with the model predictions. However at large x in the Au nucleus the nuclear modification factor rises strongly with increasing centrality. This is not yet understood.

PHENIX has made first measurements aimed at comparing the $\phi \rightarrow e^+e^-$ (120
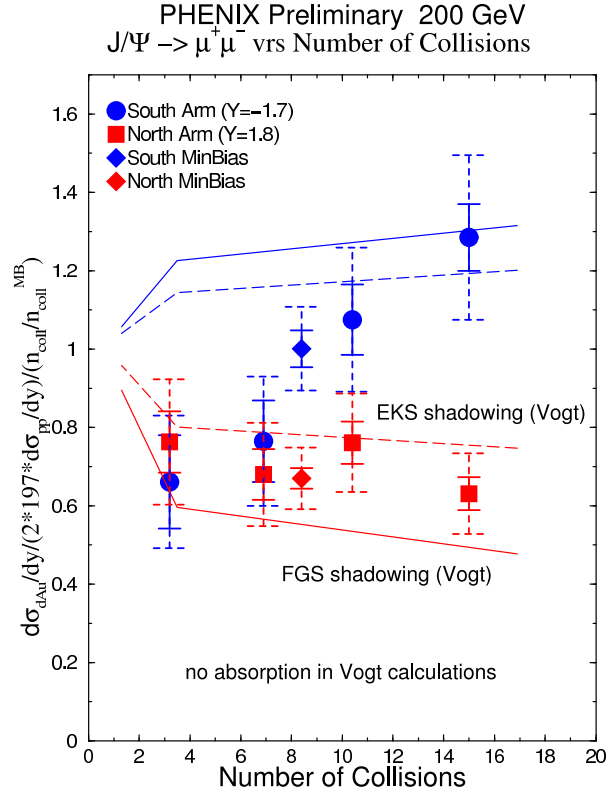
Figure 9. Centrality dependence of the nuclear modification factor for 200 GeV d+Au collisions. See the text for discussion.

events) and $\phi \to K^+K^-$ decays (207 events) for 200 GeV d+Au collisions [13]. Within the fairly large errors, the yield and transverse mass distributions agree for the two channels.

Finally, there has been a search for the anti-pentaquark via the $\bar{\Theta} \to \bar{n} \, K^-$ channel, where the $\bar{n}$ can be detected using its annihilation in the electromagnetic calorimeter [14]. The search uses the 30% most peripheral d+Au events. At the time of the conference a statistically significant mass peak was seen at an invariant mass of 1.54 GeV. But, after an independent analysis did not see the peak, it was found that the original analysis lacked a necessary timing correction which, when applied, caused the peak to fall below statistical significance.

[1] Christian Klein-Boesing on behalf of the PHENIX Collaboration, these proceedings.
[2] Felix Matathias on behalf of the PHENIX Collaboration, these proceedings.
[3] julia Velkovska, these proceedings.
[4] Jan Rak on behalf of the PHENIX Collaboration, these proceedings.
[5] Anne Sickles on behalf of the PHENIX Collaboration, these proceedings.
[6] M. J. Tannenbaum on behalf of the PHENIX Collaboration, these proceedings.
[7] Mike Heffner on behalf of the PHENIX Collaboration, these proceedings.
[8] Justin Frantz on behalf of the PHENIX Collaboration, these proceedings.
[9] Ming X. Liu on behalf of the PHENIX Collaboration, these proceedings.
[10] Sean Kelly on behalf of the PHENIX Collaboration, these proceedings.

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[13] Richard Seto on behalf of the PHENIX Collaboration, these proceedings.

[14] Christopher Pinkenburg on behalf of the PHENIX Collaboration, these proceedings.